GREEN PAPER

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Urban Air Quality

by Curtis Moore

Scarcely any city in the world has managed to avoid the modern scourge of air pollution. Even cities once famed for pristine, uncontaminated air — Buenos Aires, Denver and Madrid, for example — are now regularly besieged by air so polluted that it can kill and hospitalize the otherwise healthy, as well as the sick and infirm. But it needn't be so, for cities and nations throughout the world are beginning to deploy a wide range of strategies that successfully cope with air pollution. They range from parking bans and no-drive days to massive, legally mandated programs to install advanced pollution controls on power plants. Few of these efforts achieve perfect success, but many work remarkably well — so well, in fact, that they sometimes escape notice.

QUIET SUCCESSES

In the United States, for example, motorists abandoned leaded gasoline — the cause of most lead-based air pollution — with such completeness that the vast majority of service stations no longer sell it. Because lead has all but disappeared as a gasoline additive in the United States, its average concentration in the blood of children has dropped by nearly half. Although the makers of leaded gasoline and the lead additive warned that fuel prices would rise and supplies shrink, neither happened. Today's U.S. driver scarcely notices the absence of this poisonous fuel, if he even knows that it ever existed. Reductions in atmospheric concentrations of lead has been "one of the greatest environmental successes" says Michael Walsh, a consultant to the governments of China, Sweden, Switzerland and other nations.

Indeed, the phase-out of leaded gasoline has helped bring a new generation of even cleaner "environmental" fuels to the market. These gasolines have been reformulated to eliminate up to 90 percent of the fuel's benzene and other toxic constituents, with the result that air pollution levels in many American cities dropped up to 15 percent within only a year or so after mandated sales took effect. But successes are not limited to programs for switching fuels.

In Japan, pollution reduction technologies such as smokestack "scrubbers" — devices that can remove up to 95 percent of the sulfur pollution from smokestack gases — were installed in power plants throughout the nation. These reduced emissions of sulfur dioxide — a pollutant created when sulfur-bearing fuels like coal and oil are burned — by nearly 40 percent between 1974 and 1983, despite sharp growth in the economy. In France, national emissions of sulfur dioxide dropped by roughly 75 percent after those fuels were replaced by nuclear power.

Not all nations are willing to adopt nuclear power, of course, just as many are unwilling to mandate the installation of add-on pollution control devices. What works in one city or nation may be ill-suited to others. But increasingly, there is a wide range of solutions available for an equally wide range of problems, yielding remarkable progress in some areas, though not all.

The Hazards of Air Pollution

The World Health Organization (WHO) estimates that 70 percent of the global urban population breathes air that is unhealthy at least some of the time, while another 10 percent breathe air that is "marginal." But even in the United States, where air pollution levels tend to be considerably lower than in the cities of many developing nations, studies by researchers at Harvard University place the number of deaths caused by air pollution at between 50,000 and 100,000 per year.

Pollution affects children more than adults, and poor children — who are exposed to more kinds and higher levels of pollution — are affected most of all. Studies demonstrate that children who live in cities with higher levels of air pollution have smaller lungs, miss more days of school because of illness and are hospitalized more often. Children's smaller body weights and developing organs put them at greater risk, also. So do their habits; infants suck indiscriminately on contaminated objects; older children play on streets filled with car fumes and lead exhaust.

In 1980, for example, the industrial city of Cubatao, Brazil, reported that because of air pollution, 40 of every 1,000 babies born in the city were stillborn; another 40, mostly deformed, died in the first week of life. In the same year, with a population of 80,000, Cubatao had some 10,000 medical emergencies involving tuberculosis, pneumonia, bronchitis, emphysema, asthma, and other respiratory ailments.

In metropolitan Athens, Greece, the death rate jumps 500 percent on the most polluted days. Even in areas remote from industrial facilities, air pollution can be damaging. In the rain forests of Africa, for example, scientists report acid rain and smog levels as high as those of central Europe, probably from the regular burning of the vast grasslands to clear land. Vivid examples like these have accelerated efforts throughout the world to curb urban air pollution.

Specific Air Pollutants

Since the 1970s, U.S. air pollution policies have tended to focus on the control of a handful of the most serious urban pollutants: particulates (smoke and soot), hydrocarbons, sulfur dioxide, nitrogen oxides, ozone (photochemical smog), carbon monoxide and lead.

Carbon monoxide. The World Health Organization has found that carbon monoxide regularly reaches unhealthy levels in many cities, can result in decreased fetal weight, increased perinatal mortality and brain damage, depending on the length of time a pregnant woman was exposed and the concentration in the air.

Vehicle exhaust accounts for nearly all of the carbon monoxide emitted in many urban areas. Successful carbon monoxide reduction strategies therefore rely chiefly on auto emission controls such as catalytic converters, which change most of the carbon monoxide to carbon dioxide. Such controls have substantially lowered emissions and ambient carbon monoxide concentrations in cities throughout the industrialized world: in Japan, ambient carbon monoxide levels fell approximately 50 percent between 1973 and 1984, while in the United States carbon monoxide levels fell 28 percent between 1980 and 1989, in spite of a 39-percent increase in vehicle-kilometers travelled. However, most of the developing world is experiencing increases in carbon monoxide levels as vehicle numbers and traffic congestion rise. Rough estimates by WHO indicate that unhealthy carbon monoxide concentrations may exist in approximately half of the world's cities.

Nitrogen oxides. Created when the heat of combustion causes the oxygen and nitrogen found in the air to combine with one another, nitrogen oxides pose multiple threats. By themselves, these oxides cause lung damage. After reaction in the atmosphere, they form extremely fine particles of nitrate that penetrate to the lung's deepest recesses. These same nitrates combine with water, whether moisture in the lungs or vapor in clouds, to form acids. Finally, the oxides react in sunlight with unburnt gasoline fumes and other hydrocarbons to create ground-level ozone or "smog," the reddish brown haze that cloaks most of the world's cities.

Sulfur dioxide. Sulfur dioxide emissions arise predominantly from the combustion of sulfur-containing fossil fuels — mostly coal — for electricity generation or residential heating. The U.N.-sponsored global Environmental Monitoring System estimated in 1987 that two-thirds of urban residents lived in cities where the ambient sulfur dioxide concentration was at or above the WHO limit. An acrid but colorless gas, sulfur dioxide can trigger asthma attacks and, as it stays in the air, reacts to form fine particles and acids.

Particulate matter. Often referred to merely as smoke or soot, particulate matter is often the most obvious of air pollutants, and usually one of the most dangerous as well. The U.N.-sponsored global Environmental Monitoring System estimated in 1987 that 70 percent of the world's urban population lived in cities where the level of suspended particulates exceed WHO guidelines.

Some particulate matter pours out of industrial chimneys as thick black smoke, but the most dangerous of these pollutants are "fine particulate" — specks so small that they penetrate to the deepest recesses of the lungs. Most of these fine particles are formed with other pollutants, especially sulfur dioxide and oxides of nitrogen, and change chemically to form nitrates and sulfates. Depending on the city, up to half of all human-caused particulates arise from conversion of sulfur dioxide to sulfate particles in the atmosphere. In other cities, nitrates — created by a similar process from oxides of nitrogen — can form one-third or more of the particulate matter.

Hydrocarbons. Sometimes called "volatile organic compounds" (VOCs) and also referred to as "reactive organic gases" (ROGs), hydrocarbons are unburnt gasoline fumes and byproducts of incomplete combustion. Other hydrocarbons, some of which cause leukemia, cancer or other life-threatening diseases, range from dry cleaning fluids to industrial degreasing agents.

Ozone or photochemical "smog". Consisting of literally hundreds of chemicals that are contained in smog, ozone forms when the urban soup of hydrocarbons reacts with oxides of nitrogen. But because one of them, ozone, is the most prevalent, governments use it as the yardstick for determining oxidant concentrations generally. Ozone is such a powerful oxidant (chlorine is another) that some cities use it to disinfect drinking water supplies. Many scientists consider it the most toxic of the common air pollutants, so noxious that in laboratory experiments to test ozone's effects, one of every 10 volunteers must be removed from exposure chambers used in experiments because of respiratory distress. In laboratory animals, ozone causes scarring and cell damage similar to that found in smokers. As emissions of both oxides of nitrogen and hydrocarbons have escalated, levels of even rural ozone have doubled, and are now approaching toxicity levels for many species.

Lead. A silvery grey metal that is toxic in every known form, lead is an especially acute threat to children under six years of age, who have ingested it, usually in the form of paint chips from interior housing walls. The heavy metal destroys intelligence, retards growth, reduces the ability to hear and perceive language, and diminishes concentration. Even exposure to exceedingly low levels seems to be associated with subsequent intellectual deficiencies. Because the primary source of lead is from the exhausts of vehicles fueled with leaded gasoline, it is found everywhere cars, trucks and buses go. Even in nations where leaded gasoline has been successfully banned, dust remains contaminated from decades of use. In Mexico City, for example, seven of 10 newborns were found to have blood lead levels higher than the WHO norm.

Besides lead, a host of other toxic substances adds to the pollutant load in urban areas. These range from asbestos and heavy metals (such as cadmium, arsenic, manganese, nickel and zinc), to a wide array of organic compounds (such as benzene and other hydrocarbons, and aldehydes). U.S. companies emitted at least 1.2 million metric tons of air toxics in 1987. The U.S. Environmental Protection Agency estimates that exposure to these pollutants causes between 1,700 and 2,700 types of cancers per year.

Pollution Control Programs

The use of motor vehicles causes more air pollution than any other single activity, causing nearly half of the human-caused nitrogen oxides, two-thirds of the carbon monoxide and about one-half of the hydrocarbons in industrialized countries, as well as virtually all of the airborne lead in developing nations. In most industrialized nations, utility power plants account for up to two-thirds of sulfur dioxide emissions and from one-third to one-half of the total emissions of most other air pollutants. Thus, the first two priorities of many pollution control programs are motor vehicles and power plants, though in some developing nations, attention first focuses on controlling pollution from the widespread use of cheap and plentiful coal for residential cooking and heating.

Short of those cities where walking and bicycling remain the dominant form of transportation, it is nearly impossible to seriously attack air pollution without taking aim at the tailpipes of scooters, mopeds, cars, trucks and buses. Even in cities where bicycles predominate, the number of cars is growing rapidly. More than 500 million automobiles and commercial

THE EMISSIONS CONTROL REVOLUTION

Twenty years ago, commercially available catalytic converters didn't exist. Indeed, when leaders in the United States first proposed the emissions standards that forced their development, the president of General Motors, the world's largest manufacturer of motor vehicles, said, "Accomplishment of these goals, as far as we know, simply is not technologically possible." Yet since the late 1980s, virtually every new car, van and light, or "pickup," truck sold in the United States has been equipped with a catalytic converter, making it possible to reduce emissions of volatile organic compounds and carbon monoxide by about 85 percent, and nitrogen oxides by about 60 percent over the life of a car.

Widespread adoption of state-of-the-art emissions controls for cars and trucks in the 1980s began with the United States and Japan standing alone as the only nations with advanced pollution control programs for cars. By 1993, however, there has been a 180-degree reversal: every major group of nations (although not every country within the group) has adopted tougher tailpipe controls, including some nations in the former Soviet Union.

The rapid spread of U.S.-type controls began in Western Europe, when Germany, Switzerland, Austria and Sweden became increasingly alarmed at the rapidly accelerating environmental damages attributed to air pollution. Germany began lobbying within the Common Market for tighter standards, while the remaining three nations — all non-members of the European Economic Community, and thus free to act on their own — made it clear that they would unilaterally require catalyst-based controls. This combination of pressure both inside and outside culminated in a 1989 decision to require U.S. standards for all Common Market cars effective with model year 1992.

This turn-about came none too soon, for in 1988, the global car population had exceeded 400 million for the first time in history. While growth was greatest in the rapidly industrializing areas of Asia, new car sales records had also been set, even in highly developed areas such as Western Europe. With commercial vehicles included, over 500 million vehicles were on the world's roads by 1989 — a ten-fold increase since 1950.

There seems to be no end in sight for this phenomenal growth in the number of cars and trucks. Global population is projected to double that of 1960 by the year 2000, driven by a more than two-fold increase in Asia and an almost 150-percent increase in Latin America.

As the ravages of air pollution became more apparent in the major cities of the developing world, nations such as Mexico, Brazil and Taiwan have also adopted catalyst-based controls. Thus by the end of the decade, nations throughout the world will have adopted them: Japan, Taiwan and South Korea in Asia; Brazil in South America; and the Common Market countries plus Austria, Sweden and Switzerland in Western Europe. Today, four of every five new cars in the world meets advanced catalyst-based standards of some sort.

Meanwhile, in California, after lengthy hearings, the state government adopted a requirement in 1991 mandating the sale of "Zero Emitting Vehicles" (ZEVs) beginning with the 1998 model year.

ZEVs are merely one part of a complex matrix of increasingly tighter standards that will be phased in with time. The first ZEVs must be on the road by 1998, when they must account for 2 percent of new car sales, rising to 10 percent in the year 2003. The movement to curb pollution from diesel engines, which without emissions controls emit 30 to 70 times more particulates than gasoline engines equipped with catalytic converters, has also gathered momentum.

Until recently, diesel engines were virtually unregulated worldwide, but new standards adopted by the United States and Europe have spurred development of technologies that promise to greatly improve diesel emissions performance. Traps, or devices for capturing diesel soot so it can be destroyed, have been developed, as have specially modified catalytic converters. In Japan, the government is regulating the fuel as well as the engine, adopting what have been described as the world's toughest fuel-quality requirements.

Only increasingly tighter standards have made it possible to hold automotive air pollution in check as the number of vehicles on the road — and most importantly the number of kilometers they travel — has risen rapidly. What the future will hold is unclear. Inevitably, either tailpipe emissions must begin to approach zero or growth has to be controlled, or both, if major cities are to have air that is healthy to breathe.

vehicles now ply the world's roads, 10 times more than in 1950. And according to recent projections, the global vehicle population will double over the next 40 years to about one thousand-million. Much of this growth will take place in developing countries, where demand for automobiles is expected to increase by over 200 percent by the end of the century, greatly exacerbating current pollution problems, especially in urban areas.

Where leaded gasoline is still widely used, one of the most effective pollution control strategies has been to either ban the additive outright or sharply reduce the permissible level in gasoline. When this happened in the United States, the use of leaded fuel declined more than 50 percent from 1976 to 1980, dropping blood-lead

Implementation Rate for Zero and Near-Zero Emitting Vehicles
[TLEVs, LEVs, ULEVs and Zevs]

The chart below shows the rate at which car-makers must begin selling the newer, less polluting vehicles being required by California, using hydrocarbon emisions as an example. For example, in 1998 48 percent of new car sales must meet an emissions limit of 0.25 grams per kilometer; another 48 percent must meet the low emitting vehicle (LEV) standard of 0.075 grams per kilometer; 2 percent must meet the ultra-low emitting vehicle (ULEV) standard of 0.040; and another 2 percent must be zero-emitting vehicles (ZEVs). The average of all new cars must be 0.157 grams per kilometer.

Model Year	0.39	0.25	TLEV 0.125	LEV 0.075	ULEV 0.040	ZEV 0.00	Fleet Avg. Std.
1994	10%	80%	10%				0.250
1995		85%	15%				0.231
1996		80%	20%				0.225
1997		73%		25%	2%		0.202
1998		48%		48%	2%	2%	0.157
1999		23%		73%	2%	2%	0.113
2000				96%	2%	2%	0.073
2001				90%	5%	5%	0.070
2002				85%	10%	5%	0.068
2003				75%	15%	10%	0.062

levels by 37 percent. Some cities and nations are pressing for the use of alternative fuels that burn cleaner than conventional petroleum-based gasolines and diesels. Options range from reformulated “environmental” blends that reduce both their volatility — and thus volatile organic compounds emissions — and the concentrations of benzene and other toxic components. Another option is to “oxygenate” the fuel by adding alcohol. Such “gasohols” burn more completely, thus lowering emissions of carbon monoxide. Diesel fuels with reduced sulfur levels emit less sulfur dioxide as well as other pollutants. These reformulated fuels can, in and of themselves, cut various emissions by up to 30 percent, as they have in the northeastern United States where they were first required in the late 1980s.

Better still are non-petroleum alternatives such as methanol, ethanol, compressed natural gas or liquified petroleum gas, hydrogen or electric batteries, because they eliminate tailpipe pollution altogether.

New Kinds of Motor Vehicles

With the state of California requiring more stringent standards in pollution control devices for automobiles and trucks in the 1970s, manufacturers of catalysts began to improve their products by developing the means to preheat catalysts, thus making them start sooner and eliminate even more pollution.

California’s requirements also triggered a flood of innovation in the vehicle industry. Although electric cars were among the first vehicles of the century, the technology languished until California mandated sales of “zero-emitting vehicles,” or ZEVs, beginning with the 1998 model year. Since then, virtually every major car-maker in the world, ranging from BMW to General Motors, has developed a battery-powered vehicle, and so have some utilities. To aid the American car makers, the U.S. government has given the U.S. Advanced Battery Consortium $8 million to develop low weight, high-power batteries.

The ZEV mandate is merely one component of a complex mixture of tougher tailpipe standards being required by California in an attempt to sharply reduce pollution from cars, trucks and buses. The state’s regulations also require sales of low emitting vehicles (LEVs), ultra-low emitting vehicles (ULEVs) and transitional low emitting vehicles (TLEVs), all calculated to force not only cleaner cars into the marketplace, but cleaner fuels as well. So far, the California program is succeeding.

Extraordinary and rapid progress has also been made in the development of super-clean natural gas engines. Although cars and trucks fueled by natural gas number in the hundreds of thousands, with huge fleets in Italy, New Zealand and the former Soviet Union, none of these had been optimized to reduce tailpipe air pollution. With the advent of the California LEV/ZEV program, however, car makers and natural gas suppliers began collaborating in the development of vehicles designed from the ground up to burn natural gas — and with astounding results: after 80,000 kilometers, vehicles not only met the ULEV standard but were 96 percent below it.

Still, practical reasons suggest that battery-powered cars, once marketed, are likely to gain and retain an increasing share of the light duty market. Following California's initiative, 11 other U.S. states, most in the Northeast, committed to adopting the ZEV/LEV standards. If these commitments endure, there should be about 2 million ZEVs on the road in the United States in the year 2003. Assuming further that each car is driven the current U.S. average of 48 kilometers per day, consuming 0.5 kilowatt hours per 1.6 kilometers (the consumption of Chrysler's battery-powered TEVan, the most power hungry of the electric vehicles developed so far), each car would consume 15 kilowatts during an overnight, eight-hour recharge. The aggregate consumption of this fleet would be about 4-million kilowatts, or a one percent increase in peak demand. Converting the entire fleet to battery operation would increase electricity requirements by roughly 25 percent — but decrease carbon dioxide emissions by a like amount, assuming the current mix in electricity consumption.

Thus, battery-powered cars would deliver double-good news: local pollution such as smog and carbon monoxide would be reduced by eliminating tailpipes; global warming pollution like carbon dioxide would be curbed by substituting more efficient central power stations for conventional internal combustion engines. If the fleet were converted to battery-powered vehicles more efficient than the TEVan, reductions might be even greater.

Other Means of Dealing with Vehicular Pollution

For many urban areas, equipping jitneys, scooters and cars with advanced controls, while effective, simply doesn't reduce air pollution quickly or substantially enough. These cities have crafted a wide array of programs, ranging from no-drive days to bans on city parking, collectively known as "transportation controls measures" (TCMs).

Many TCMs focus on reducing traffic congestion, using systems that range from physical methods — coordinated traffic lights, paired one-way streets and separate carpool or bus lanes — to economic incentives, for example, "congestion pricing" that charges motorists for driving on roadways during peak traffic periods.

Access restrictions. In 1977 Buenos Aires began restricting private vehicles from entering the downtown district from 10 a.m. to 7 p.m. on weekdays. Buses and taxis are allowed on a few streets. The ban combats the congestion and air pollution caused by the one million people who flood central Buenos Aires each working day. Initially police barricades were used to enforce the measure; now small signs explaining the policy are sufficient.

Partial or total car bans also have been established in most large Italian cities — including Rome, Florence, Naples, Bologna and Genoa — as well as in many smaller ones. From 7:30 a.m. to 7:30 p.m., only buses, taxis, delivery vehicles and cars belonging to area residents may enter the central districts of Rome and Florence. Similar bans are also in effect in Athens, Amsterdam, Barcelona, Budapest, Mexico City and Munich. Within a decade, Bordeaux, France, intends to exile motor vehicles from half of the city's streets, reserving these thoroughfares for pedestrians and cyclists.

Parking bans. Parking bans limit the number of cars that can park in an area, but have no effect on the number that drive through. One way to ward off problems caused by an overabundance of vehicles is to keep them out of urban centers altogether. Auto-free zones — as a way to reduce air pollution, boost tourism, and enhance the quality of life — are becoming increasingly popular in Europe. The experience in the United States has been more limited; car-restricted zones are generally confined to small tourist or shopping districts and have little impact on a city's overall transportation patterns.

Traffic "cells." Gothenburg, Sweden, divided its city center into five pie-shaped sectors in 1970 as a way to limit through-traffic and encourage public transportation. Emergency vehicles, mass transit vehicles, bicycles and mopeds can pass freely from one zone to the next, but automobiles cannot. Reduced auto traffic in downtown Gothenburg has led to improved transit service and a lower accident rate. This so-called traffic cell approach, which originated in Bremen, Germany, is also used in Groningen, Holland, and Besançon, France.

No-drive days. Late in 1991, Rome, Milan, Naples, Turin and seven other Italian cities declared war on pollution by limiting the number of cars on the road. Under the plan, cars with odd-numbered license plates are banned from driving on one day, and cars with even-numbered plates are banned on the next. Many motorists, bridling at any restrictions on their right to drive, have ignored the odd-even rule. On a single day in December, police officers wrote 12,983 citations, fining mavericks for driving on the wrong day or for tampering with their plates. With rigid enforcement, however, Italy's environment minister, believes the alternate-day ban can reduce pollution by 20 to 30 percent.

The city government of Los Angeles, California, has also come up with a plan similar to that of the Italians. A controversial contingency plan has, in fact, been drafted to help meet the standards of a new Clean Air Act. Starting in the year 2000, "no-drive" days will be imposed in Los Angeles as a last resort to lower ozone and carbon monoxide levels. If the plan is implemented, every motorist will have to leave his or her car at home one day a week, depending on the license-plate number.

Bicycling. Already the world's most common form of transportation, bicycling is enjoying a resurgence as governments seek to encourage it even further through special programs. The 800-million-plus bikes on this planet outnumber passenger cars by roughly two to one, but to foster even greater ridership, nations such as the Netherlands, Denmark, Belgium and Germany are expanding their networks of bikeways, each with rights-of-way separate from roads. Special parking spaces, renting bikes with a guaranteed return deposit and even bicycle parking garages encourage the use of bikes. Such programs have a tremendous effect on the way people see their options in transportation. For example, bicycle riding in Erlangen, Germany, doubled after 160 kilometers of bike paths were built. Many Chinese cities have five- and six-lane bicycle avenues. In fact, biking is so prevalent in China that traffic monitors in the city of Tinajin counted more than 50,000 bicycles passing through a single intersection in one hour.

Flextime. During the 1984 Summer Olympics, Los Angeles staggered work hours, reducing air pollution to the lowest levels in recent memory. Now many cities are seeking to curb pollution by starting the regular workday or school day an hour or two earlier, or by ending it earlier, thus reducing congestion. Others are encouraging four-day work weeks as another traffic reduction strategy. At the Los Angeles County Department of Public Works headquarters, for example, employees work 10 hours a day Monday through Thursday. On Fridays the entire building is shut down, not only cutting smog and traffic, but also saving $1.7 million a year in operating costs.

Telecommuting. Another strategy, "telecommuting," or allowing employees to work at home by using telephone hookups and computers, reduces office overhead while saving workers both time and money. Los Angeles officials hope to eliminate three million work trips a day through work-at-home programs and telecommuting. The Center for Futures Research predicts that five million Americans hold computer-related jobs that could be done at home by 1993. And a Southern California Association

STUDIES IN SUCCESS

Curitiba, Brazil. *In South America, the fame of a Brazilian city that advertises itself as the "environmental capital" is spreading across the continent. With a metropolitan population of 2.3 million, Curitiba has managed to provide no-cost medical, dental and child care, create a recycling rate that's among the world's highest, and drive down the rates of environmentally related diseases, all despite runaway inflation and the grinding poverty in the surrounding countryside. Yet the linchpin of these and many other accomplishments is, of all things, an extraordinary bus system. Though the city's per capita automobile ownership is higher than for all but three Brazilian cities, its transportation fuel consumption — and hence its air pollution — is 25 to 30 percent lower. The reason: buses here are faster, cheaper and more comfortable than cars. The buses move people with the same efficiency as a modern subway, but at only one to 3 percent of the cost. In all, buses carry more than 900,000 riders a day. Because so many people use the system, it is one of the few public transit systems in the world that pays for itself.*

Curitiba started building its bus system in the 1970s under the leadership of its mayor, Jaime Lerner, an architect and urban planner. He created a winning mix of fast express arteries, local feeder buses and special routes for circulating in the downtown. The city allows only high-rise apartment buildings near major arteries, and each building must devote the bottom two floors to stores. The nearby stores minimize the need for residents to travel, and the high-rises give large numbers of commuters quick access to buses.

Within the last three years, Curitiba has added an ingenious idea that makes its buses even faster: boarding tubes. Resting beside the road, these steel-and-glass cylinders are almost 3 meters in diameter and 10 meters long. Instead of climbing steps onto the bus and then paying the fare, passengers insert tokens to board, then simply wait in the tube for the specially designed bus to dock.

After a short wait — usually only about five minutes — a chime sounds, then a specially designed Volvo bus docks with the tube with the aid of a photoelectric eye. Two 1.3-meter wide doors slide open, stainless steel ramps lower, and, within seconds, riders are aboard a bus with sculpted seats, wide glass windows and liberal amounts of stainless steel mimicking the world's newest subway systems. The bus, often a triple-length version able to carry 270 passengers, speeds away and within 20 minutes passengers have made the 12-kilometer commute downtown.

Mexico City, Mexico. *A metropolis of 20 million people, Mexico City is generally credited with having the world's most unsavory air. Coping with the air pollution has required what some might consider draconian measures. These include a one-day-a-week driving ban adopted in 1989 with an aggressive ad campaign and $150 fine for violations, that has reduced pollution by about 10 percent.*

Although Mexico City residents initially complained about the program, 80 percent now want it to continue. The success of the Mexico City driving ban has encouraged two of the country's other biggest cities, Monterrey and Guadalajara, to start programs of their own.

Singapore. *This city-state may boast the world's most concerted program to reduce pollution by controlling traffic. Driving to the Central Business District (CBD) requires a special permit, which may be purchased on a daily or monthly basis. Traffic restriction in the CBD is in force from 7:30 a.m. to 6:30 p.m. daily, except on Sundays and public holidays. Police officers are stationed at gantry posts on the perimeters of the CBD to spot violations, for which fines are levied automatically. The rigid controls extend to taxis which are equipped with alarms inside the passenger compartment that sound automatically when the speed exceeds 80 kilometers per hour. All motor vehicles have to undergo annual inspections, to ensure they are roadworthy and comply with emission standards. The excellent public transportation network includes buses, taxis and a "mass rapid transit" or subway system.*

Beijing, China. *The world's sixth largest city, Beijing has mounted a wide-ranging attack on air pollution with programs to protect the city's watershed, upgrade slums, encourage bicycle use (90 percent of the kilometers travelled in the city are by bike), and eliminate local coal burning. To curb widespread use of coal, the city built two large plants to manufacture coal gas, which is piped to roughly one million homes and 600 industries.*

of Governments study found that if one out of eight workers chose to work at home, or at a nearby "satellite" work station linked electronically to a central office, vehicle delays on the region's freeways could be reduced by nearly one-third.

Inspections and maintenance. Rigorous vehicle maintenance and inspection programs, to ensure compliance, are an important adjunct to emission standards. Tampering and poor maintenance can quickly render emissions controls ineffective. Age also tends to decrease the performance of pollution equipment. Programs to retire older vehicles from the road, perhaps by offering some financial incentive, could therefore reduce auto emissions significantly.

BUILDING HOMES FROM AIR POLLUTION

Heaped near the railroad tracks at Knauf Gypsum, Germany's largest construction materials company, lies what was once a good share of the nation's air pollution. Soon, it will be made into homes.

The air pollution is in the form of gypsum briquettes — hard as rocks and roughly the size and color of eggs — that lay heaped in the winter's bitter cold and snow. These briquettes are the byproduct of smokestack "scrubbers," devices that spray pollution-laden air with a mixture of water and limestone, thus producing a sludge that in most nations is simply dumped into pits.

In Germany, however, power plants must either develop an alternative to scrubbers or find a way to use their sludge. German industry has done both, yielding one stream of innovation aimed at developing pollution controls superior to scrubbers, the other at perfecting better ways to use scrubber sludge. Knauf's homes-from-pollution process is one result.

With spring and the construction season, the briquette heaps begin shrinking as they are powdered and mixed with water to make a paste that is then sandwiched between sheets of heavy kraft paper and dried to form what is variously called "wallboard," "sheetrock," or "gypsum board."

Shipped to building sites across the nation, the pollution boards become the walls and ceilings of offices and homes. The product has been so successful, in fact, that in 1990 Knauf Gypsum opened a new plant at Sittingborne-on-Thames in Great Britain.

POWER PLANTS

Long regarded by many nations as expensive and difficult to control, power plants are increasingly becoming the target of both new technologies and new practices, and for good reason: short of motor vehicles, they are the largest aggregate source of most air pollution. In the U.S., for example, electricity generating power plants emit nearly two-thirds of all sulfur dioxide and slightly less than one-third of all oxides of nitrogen. Although figures are kept for many other pollutants, it's likely that the same is true for other emissions as well, especially particulates and heavy metals and, indirectly, ozone. The electric utility share is likely to grow globally, because demand for electricity is rising by as much as 10 percent per year in some nations, which would mean a doubling in consumption roughly every seven years.

The impact of such massive amounts of pollution on cities is difficult to sort out because many electric utilities have constructed so-called "tall stacks" — chimneys that can be as high as 396 meters — for the purpose of dispersing their pollution over hundreds of square kilometers. The result has been a widespread, but difficult-to-measure decline in air quality over large regions, which has made it difficult to establish cause-and-effect linkages between air pollution and human illness. Still, massive government-funded studies (one U.S. study cost $600 million spread over 10 years) have definitively tied power plant pollution with widespread environmental damage — acid lakes and streams, as well as dying forests, for example. Recent health studies, also conducted over large populations, have begun to link this mix of air pollution with human mortality, indicating that in the United States alone particulate pollution accounts for upwards of 50,000 deaths per year.

Thus, governments in the 1990s are beginning to focus on electricity generating power plants as large and relatively easy to control sources of air pollution, much as officials of the 1970s and 1980s looked at motor vehicles. As with cars, trucks and buses, the means of controlling power plant air pollution range from new fuels — coals that are lower in sulfur content, for example — to technologies such as smokestack "scrubbers," which reduce emissions of sulfur dioxide — the worst cause of acid rain — by 90 percent or more. Again, just as some new technologies hold the promise of eliminating motor vehicle pollution altogether, other systems could produce the same result in the generation of electricity: wind turbines, for example, can generate power at the same cost as coal — the cheapest and dirtiest fossil fuel — but with zero air pollution.

The potential for reducing air pollution by installing add-on pollution controls — an approach analogous to requiring catalytic converters on cars — is illustrated by the remarkable success of Germany. There, the public became alarmed in 1980 and 1981 by “Waldsterben,” or forest death. With an almost mythic connection to its forests, ranging from the Black Forest to the graceful Lindens of Berlin, and convinced that air pollution was killing them, Germany ordered power plants to reduce their emissions by 90 percent or more within a six-year period. The program cost about 21 thousand-million Deutschmarks ($12.6 thousand-million), but it achieved the desired result of slashing national emissions of sulfur dioxide by half.

In the process, Germany established itself as a world leader in the manufacture of both scrubbers and “selective catalytic reduction” (SCR) systems, which can reduce 90 percent or more of the nitrogen oxides that cause both smog and acid rain. German power plants were upgraded, boosting their efficiency by about 12 percent. Throughout the world, scrubbers have been installed or are under construction at plants producing approximately 104,500 megawatts of electric capacity, according to the International Energy Agency.

New Technologies

A number of relatively new technologies promise substantial reductions in emissions compared to current systems. Operating on hydrogen, some can, in fact, achieve an emission level of zero, or so close to it that the difference can’t be measured with today’s instruments. Even operating on fossil fuels such as natural gas, these technologies can achieve zero emissions of some pollutants and near-zero levels of others.

These stationary source technologies include:

Combined-cycle turbines. Gas-fired combined-cycle turbines are capable of generating electricity that reduces air pollution by between 50 and 99 percent compared to most coal-burning power plants. (In combined-cycle systems, the fuel is used to run two turbines, one powered by the hot combustion gases, the other by steam — a concept akin to using gasoline to power your car’s engine, then harnessing the tailpipe exhaust to run another machine.) Because they’re fueled by natural gas, such systems produce no emissions of sulfur dioxide or particulate matter. If equipped with an advanced pollution control system called selective catalytic reduction (SCR), emissions of oxides of nitrogen are only one-tenth or less of those from other new power plants.

Aircraft-derivative turbines. Such combined-cycle systems can require years to build and hundreds of millions of dollars. Fortunately, they have smaller and less expensive cousins known as aero-derivative turbines because they are based on the jet engines used on Boeing 747s and other modern aircraft. Power plants using aircraft-derivative turbines can be built on smaller scales and in the space of months, not years. Better still, they are theoretically capable of curbing air pollution —even hard-to-reduce carbon dioxide — by another 20 to 90 percent.

Fuel cells. Although fuel cells (devices for converting fuel to electricity chemically, not unlike a battery) are only now entering commercial production, present models can achieve efficiencies of roughly 40 percent — that’s more than double the level of the average automobile engine, and significantly higher than conventional power plants. Again, because they’re operated on natural gas or other cleaner fuels, emissions of sulfur dioxide and particulate are zero. Moreover, fuel cells are astonishingly compact — some are no larger than a tabletop copier — and virtually silent, so they can be built in the heart of offices, factories or even homes.

Both aircraft-derivative turbines and fuel cells can be deployed in combined heat and power applications, allowing energy that would otherwise be wasted to be put to uses ranging from space heating or chilling to the generation of process steam for industrial operations. Total efficiency climbs to 80 or even 90 percent, nearly three times current levels, and pollution drops accordingly.

These new systems are being marketed by some of the world’s largest and most technologically sophisticated companies. Combined-cycle turbines, for example, are offered by both General Electric and Siemens. Plants that use these combined-cycles systems in concert with new ways of gasifying coal — and, thus eliminating much of the pollution — include Asea Brown Boveri, Shell, Lurgi and Texaco. Manufacturers of fuel cells or associated equipment include United Technologies, Fuji Electric, Westinghouse, Siemens and Toshiba, to name but a few.

Zero-polluting wind turbines that generate electricity for the same or less cost than coal, can be bought from U.S. Windpower of Livermore, California, while solar cells are being sold by more than a dozen companies, including Siemens Solar, Accurex, Solarex and Texas Instruments.

Many nations are mandating or encouraging the deployment of these technologies in order to reduce air pollution. Belgium and England are each installing wind turbines, while Germany and Japan are pursuing solar photovoltaics. Power plants using advanced combined-cycle systems in conjunction with selective catalytic reduction systems are being constructed in Japan and the United States, while pre-commercial fuel cells are being installed in California, Japan, Germany and the Netherlands. Meanwhile interest in curbing pollution through a different approach — preventing pollution through a variety of means — is also increasing.

Pollution Prevention

U.S. economist Robert Hamrin calls pollution prevention "the most important single force in...causing American industry to rethink and change established production and management processes." Since mid-1990 nearly two of every three corporations say they've launched major environmental initiatives. The 3M Corporation, for example, has saved $530 million since 1975, when it established the "3P" program, which stands for "Pollution Prevention Pays." The chemical company has prevented more than 575,000 tons of pollution. "Pollution prevention became a way of life," according to one corporate case history, boosting the company's profits and competitiveness.

At a 3M pharmaceutical plant in California, substituting a water-based tablet coating for one based on solvents saved $120,000 per year, while reducing air pollution. At a Du Pont plant in Beaumont, Texas, for example, a pollution prevention program cut air emissions by roughly 27 million kilos per year, while saving nearly $1 million in annual manufacturing costs. About 1,200 U.S. companies have voluntarily pledged to reduce nearly 160 million kilos of 17 priority chemicals.

Demand-Side Management

The U.S. Environmental Protection Agency (EPA) has found many U.S. utilities to be enthusiastic partners in programs to reduce pollution by curbing electricity demand. As the costs of construction and capital have soared, utilities have been increasingly anxious to meet rising demand for electricity through conservation, usually called "demand-side management" or DSM. From the environmental perspective, DSM is merely another way of stopping pollution by preventing it in the first place. But to the utilities and their customers, DSM is popular because everybody seems to win.

A case in point is the General Foods plant in Framingham, Massachusetts, where about 76 million liters of ice cream is manufactured each year. As Boston-Edison's 55th largest consumer of electricity, the plant's size, age and inefficiency made it a prime target for the utility's "Energy Efficiency Partnership" program. Under it, Edison helps companies upgrade and modernize equipment, thus reducing their electricity consumption. Since state rules allow Edison to recoup both the costs of such programs and a profit (with a slight increase in rates), the utility is able to make money off electricity which is never sold — so-called "negawatts."

Edison also helped Kraft, Inc. develop a comprehensive modernization program that included new freon-free refrigeration equipment, high efficiency motors for homogenizing and pasteurizing equipment and a lighting system with energy saving bulbs and lighting controls. These reduced electricity consumption by a third and, with the Edison rebates, paid for the $3.6 million modernization program within two years. It was a classic win-win-win case. The energy-savings measures paid for themselves within two years and, after that, began actually making money for Kraft. Boston-Edison also saved money, because it was able to avoid the construction of a new and expensive power plant. The environment benefitted because huge amounts of both air and water pollution were eliminated. Stories like this are being replayed regularly in the United States, and they extend far beyond merely electric utilities.

Market-Based Systems

Recently, pollution prevention efforts have focused on targeting entire segments of the U.S. economy, using programs with colorful names like "Golden Carrot" and "Green Lights." All are aimed at harnessing Yankee ingenuity in the quest for cleaner, better, faster and cheaper products — and reducing air pollution in the process. Green Lights was launched by the U.S. Environmental Protection Agency in 1991 to reduce pollution by saving lighting energy. Corporate, utility and government partners enter into contracts with EPA in which they agree to upgrade 90 percent of their existing lighting within five years of signing. Since lighting accounts for roughly one of every five kilowatts of electricity consumed in the United States, even small reductions in use can yield large savings in air and water pollution.

In less than two years, the EPA signed up more than 650 participants, including many of the largest U.S.

corporations, representing almost 279 million square meters of office space — roughly 3 percent of the national total. Participants were expected to cut their electricity use by 12 thousand-million kilowatts hours per year, saving $870 million. The Gillette Company, for example, retrofitted its 4,650 square meter facility in California and shaved 61 percent off its energy bill. EPA estimates that by 2000, at least 4.65 thousand-million square meters of U.S. facility space will be committed to energy-efficient lighting programs, avoiding the emission of millions of tons of carbon dioxide, sulfur dioxide and nitrogen oxides.

Green Lights' success has spawned other voluntary, "market-based" programs. One is the "Energy Star Computer," which seeks to create a market for computers that automatically "power down" when not in use, a technology pioneered for use in laptop computers. The technology adds virtually nothing to the price of a computer, but can cut its consumption by 80 percent. Since computers currently account for roughly five percent of commercial electricity consumption, this is no small accomplishment. The Energy Star program has proven so popular that it may become a defacto industry standard.

Perhaps the most imaginative of the market-based programs is the "Golden Carrot," in which a handful of utilities and governments pooled their money to offer a $30-million bounty to the company that could mass produce a home refrigerator that was both CFC-free and super efficient. Since refrigerators consume 20 percent of all U.S. electricity and up to one-third of the electricity in the average home, the projected savings were huge. Whirlpool won the competition, and attention is now shifting to adapting the approach for heat pumps, washing machines and a range of other energy-intensive products.

Conclusion

Twenty-five years ago, it would have been laughable to suggest reducing air pollution by regulating washing machines or light bulbs. But the inexorable growth in both people and pollution has left the governments of the world, especially those of cities, with little choice. The result is a profusion of new technologies: cars, power plants, and paints that generate zero or near-zero air pollution, and light bulbs, washing machines and lawn mowers that do the same. The new environmental technologies are becoming so common that we scarcely recognize them as such anymore. Where it will all end is impossible to say. Indeed, it's possible that this new industrial revolution will, like the air pollution and other imperatives forcing it, end only when they do. And that could be never.

GLOSSARY

Acid rain: *Some pollutants, especially oxides of sulfur and nitrogen, are transformed by time and sunlight into compounds that react with water in the air to form acids. These pollutants, often referred to as "acid rain" also include snow, fog and mist, as well as dry compounds that react on the surfaces of leaves or the earth. These acids not only poison lakes and streams, killing fish and other animal life, but corrode metals and paints, and literally dissolve some stone buildings and monuments (see sulfur dioxide).*

Carbon dioxide (CO^2): *Formed when carbon-rich fuels like coal or oil are burned, carbon dioxide is a colorless and odorless pollutant that is one of several "greenhouse" gases, so-called because they trap the earth's heat not unlike the panes of glass in a greenhouse.*

Carbon monoxide (CO): *When carbon-rich fuels like coal and oil are burned incompletely, the result is the colorless, odorless gas known as carbon monoxide. At high concentrations, carbon monoxide kills thousands each year, while at the lower levels found in cities, it can aggravate angina — a heart condition — and cause other damage. Motor vehicles account for roughly 80 percent of carbon monoxide.*

Hydrocarbons (HCs): *Although there are a variety of other names for this pollutant, ranging from "reactive organic gases" to "volatile organic compounds," they all refer to the thousands of different pollutants found in unburnt gasoline, dry cleaning fluids, industrial solvents and many other combinations of hydrogen with carbon. Many hydrocarbons are dangerous in their own right: benzene, a constituent of gasoline, for example, causes leukemia. Others react with oxides of nitrogen in the presence of sunlight, resulting in "smog" or "ozone" (see ozone).*

Lead (Pb): *A silvery, grey metal familiar to every person who's ever weighted a fishing line, lead is toxic in every known form and of utterly no nutritional value. Some experts believe its extensive use as a wine preservative in ancient Rome resulted in widespread mental dementia and, contributed to the empire's fall. Aside from hot spots such as smelters, modern lead pollution is most often the result of its use as "Ethyl" or other gasoline additives.*

Oxides of nitrogen (NOx): *When coal, oil, gas — even a match — are burned in the atmosphere, the heat triggers a chemical reaction that causes naturally occurring nitrogen and oxygen to combine with one another, forming a wide range of reddish-brown pollutants called oxides of nitrogen. Although some oxides of nitrogen can be attributed to the nitrogen in the fuels themselves, the bulk of them are "thermal." These gases cause respiratory damage, especially in children. Oxides of nitrogen are also transformed into exceedingly fine nitrate particles that can reach the lung's deepest recesses. Mixed with water, whether in the air or lungs, nitrates form acids (see also acid rain and particulates).*

Ozone (O^3): *Oxygen is found naturally in two forms, and ozone is one. The most common compound of life-sustaining oxygen is the two-atom molecule that constitutes roughly 20 percent of the ambient air. In the high altitudes of the stratosphere, however, a layer of the three-atom oxygen compound, ozone, blocks the radiation that streams toward earth from the sun's thermonuclear explosions. Ozone is also found close to the ground, partially because of the reaction between two common pollutants, oxides of nitrogen and hydrocarbons. An extraordinarily dangerous air pollutant, ozone is such a powerful oxidant that it is used by some cities (e.g. Los Angeles, California and Zurich, Switzerland) to disinfect drinking water supplies. The soup of air pollutants found in most cities is often referred to collectively (and incorrectly) as ozone, because that is the dominant and easiest-to-measure ingredient.*

Particulate matter (PM): *Smoke and soot are called particulate matter, but the most dangerous form of these solids are the exceedingly small "fine particles," which are small enough to penetrate deep within the lung where only molecule-thick cell walls protect the body. Often referred to as PM10 because the particulate matter is smaller than 10 microns, the bulk of the fine particles are from sulfur and nitrogen compounds that change over hours or days from gases into solids.*

Sulfur dioxide (SO^2): *Formed when sulfur, a golden yellow powder found in coal and oil is burned, sulfur dioxide is an invisible gas with a sharp acrid odor that attacks the human respiratory system and can kill asthmatics. After hours or days of mixing in the air, sulfur dioxide forms an exceedingly fine particle called sulfate, that can penetrate to the deepest recesses of the lung. Sulfate, in turn, reacts with water — whether in clouds or in lungs — to form sulfuric acid, which is frequently referred to as acid rain.*

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